LCA Methodology

Classification in LCA: Building of a Coherent Family of Criteria

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Abstract. There is a very close analogy between Life Cycle Assessment (LCA) and decision making tools such as the multicriteria approach. LCA is a particular model of a multicriteria decision making tool which is applied to environmental data. The similarities between LCA and multicriteria decision making tools are highlighted. The strict precision of multicriteria decision making tools is used to improve classification. For this, six dimensions (or axes of significance) of environmental impacts can be distinguished. The aim is to build a coherent family of environmental data from these considerations. Rules for the building of this family are proposed.

Keywords: Classification; environmental assessment; Life Cycle Assessment; multicriterial decision-making tool

1 Introduction

LCA may be used simply as an information tool or for commercial or educational purposes. However, it is generally involved in the process to aid decision making in order to select, improve or regulate systems. Whatever the purpose of the study, the aim of life cycle assessment is always a comparison (whether explicit or not) between life cycles or steps of life cycles (i.e. manufacture, use...). The evaluation of impacts cannot be absolute, it is necessarily relative and therefore comparative.

Given the diversity of the impacts of systems on the environment, it appears logical to present LCA as a multicriterial comparison of systems. From [1] and [2], we highlight the analogy between multicriterial decision making tools and life cycle assessment. LCA is a multicriterial, decision-making tool which needs to be perfected by comparing it to other models of decision-making tools.

This is the argument put forward by LCA practitioners who propose LCA as a tool to aid environmental decision making. More generally speaking, we believe that this methodology can lead to a simultaneous approach including the economic, technical and environmental performances of systems.

The **first part** of the article (chapter 2) highlights the analogy between multicriterial decision making and life cycle assessment. The **second part** (chapter 3) presents a brief state of the art of classification and explains why the impact categories chosen in a typical classification are not a coherent family of criteria. The **third part** (chapter 4) presents the dimensions of environmental consequences and gives some rules to build the criteria family.

2 The Analogies Between LCA and a Multicriterial, Decision-Making Tool

Pictet [1] proposed a multicriterial, decision-making tool which can be applied to environmental evaluation. It will be our reference model (→ *Table 1*).

Table 1: Analogy between LCA and multicriterial, decision-making model

Multicriterial decision-making model	Life Cycle Assessment [3]	
Building of the decisional model	Goal and scope definition	
Implementation of the decisional model	Inventory analysis	
	Impact assessment	**Classification**
		Characterization
		Valuation/Aggregation
	Interpretation	
Concretization of the decisional model	LCA don't perform this part of decision making Application of the decision	

We will further detail the analogy between the implementation of the model and the inventory and impact assessment steps.

In terms of decision making, the inventory analysis consists of analyzing the existing situation and evaluating the consequences of the system studied. Then, these consequences must be analyzed following their dimensions (environmental, economic, technical, social). This part of decision making can be compared with a classification in the impact assessment. In LCA, this step leads to the establishment of a list of environmental criteria (impact categories [3]) to compare systems. In multicriterial decision-making, it's called the elaboration of a coherent family of criteria. Then, all systems are

evaluated for each criterion and results are put in a matrix of performances.

We will now focus on the elaboration of a coherent family of criteria. The comparison of systems is made from several criteria grouped in a family. This family is said to be coherent if it satisfies the three requirements: Exhaustivity (completeness), cohesion and non redundancy [2].

Exhaustivity (completeness): We should not forget criteria. So, if the evaluation of two systems are equivalent as regards all criteria, the only conclusion possible is that these two systems are indifferent. If it's not the decision makers conclusion, at least one underlying criterion was forgotten.

Cohesion: When two systems are equivalent as regards to all criteria except one, the system with the best performance on this criterion must be preferred to the other system.

Non redundancy: If a criterion is excluded from a family, then one of the two previous requirements is no longer satisfied.

The coherence of the family of environmental criteria assures the validity of the comparison.

The family of criteria is not predefined. With this method, it must be built according to the objectives and scope of the study. The actors in decision making play an important role in the building of the coherent family of environmental criteria [1].

3 State of the Art of Classification

All recent classification methods use impact categories. We can't present all methods, but we will present the three major categories and their subcategories [4], [5] (→ *Table 2*).

Table 2: Some impact categories

Resources depletion	Ecological health	Human health
Renewable or non-renewable resources Water consumption Land use	Global warming Ozone depletion Acidification Eutrophication (soil, water) Ecotoxicity (soil, water) Biological diversity Photochemical pollution	Photochemical pollution Human toxicity Noise Smell

These are the commonly used impact categories in LCA. We don't pretend to be exhaustive, but the great majority of practitioners use these categories. Sometimes, human toxicity is divided into several subcategories (acute toxicity, carcinogenicity, genotoxicity, teratogenicity...) [6]. Our comments about this classification are as follows:

- Some authors use a social welfare category [5], but these impacts are indirect and social welfare can't be considered as a environmental category in our conception of LCA.
- In most LCA, these categories are predefined and the decision maker only chooses which categories he wants to take into account [1].
- Some categories are dependant (acidification and ecotoxicity, eutrophication and biological diversity, photochemical pollution and toxicity).
- Some flows are not classified into categories because there is an existing characterization method (dust).

Thus, the classification methods don't respect the exhaustivity and cohesion principles. We need to analyze impact dimensions to build our family of criteria.

4 Elaboration of a Coherent Family of Environmental Criteria: Revision of the Classification

4.1 The dimensions of environmental impacts

First of all, we must define our terminology in environmental assessment:

The **environment** is considered as the whole of the terrestrial ecosystem. Every life form belongs to the environment and all the physical mediums. Man belongs to the environment and is simply considered as one species among other vertebrates. The environment consists of multiple environmental systems in the same way as the anthroposystem is divided into anthropic systems.

Environmental flows (or elementary flows) are flows relating anthropic systems to the environment. They are directly responsible for environmental impacts [7].

The **effect** is the consequence of an action on an environmental system or on one of the components called a target [7].

The **exposure** reflects the possibility that a flow can reach a target.

There is an effect (and therefore potential impact) when the interaction between a stressor (environmental flow) with all or part of the environment leads to a change in state of the environment. For this, a target must have been reached.

The chain of cause and effect describes the successive potential effects of an elementary flow on the environment. We prefer the term **cascade of effects**. To date, the cascades of effects of substances released into (or obtained from) the environment are not completely defined. Certain levels are either unknown or hypothetical (→ *Fig. 1*).

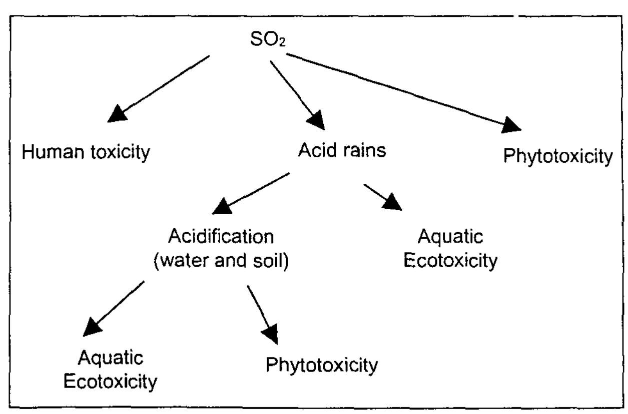

Fig. 1: Part of the sulfur dioxide cascade of effects

This cascade has five parts and five different effects. To improve classification, a better knowledge of impact dimension is needed. We have identified **six dimensions** of an impact on the environment [1] [7]:

- The targets of the impact,
- the spatial dimension,
- the temporal dimension,
- the causal dimension,
- the knowledge of environmental processes (close to the impact likelihood),
- the severity of the impact.

The first five dimensions could be called objective dimensions (scientific knowledge of the impact), whereas the last dimension integrates a subjective judgement in impact evaluation. In fact, the severity of an impact is directly related to its five objective dimensions (ecological magnitude) and the social judgement which it is made of (social importance). The first five dimensions can be used for classification enhancement so we will present them.

a) The impact targets
We have identified four primary "targets" of environmental impacts.

1) The physical mediums (surface water, groundwater, air, soil, sediments, artificial biotops),
2) the physical health of living beings (biophysicochemical impacts on the flora, the fauna, the human species),
3) the psychical health of human beings (psychical, psychological or social impacts),
4) the quality of ecosystems (damage to the patrimony of the ecosystem, reduction of biodiversity in the environmental systems). A distinction will be made concerning the impact on plant biotic systems, animal biotic systems and abiotic systems.

b) The spatial dimension
Only two scales seem to be relevant [8]:

1) **A local scale** (whose radius is to be fixed for each study according to needs, we recommend a limit of 20 km). This corresponds to the size of a canton, a small department or a large city.
2) **A global scale** (more than 20 km).

We consider, in most cases, that a **regional scale** is no longer relevant. Observation of major industrial accidents, natural catastrophes and the study of polluted sites show that the effects of the environmental flows either remain confined to a small zone or go far beyond national borders and even cross continents. Moreover, in terms of decision making, these two scales are relevant for an environmental diagnostic [9,10]. If the reduction of an impact can be reached by a regional action, a regional scale can be added (from 20 km to 1000 km).

c) The temporal dimension
A continuous time scale can be associated to this dimension. Certain impact mechanisms take place within minutes or even in seconds (acute toxicity), and others may prevail for centuries (radioactivity, greenhouse effect, persistence of ChloroFluoroCarbons CFC).
In their analyses, most authors retain short and mean term effects (less than 10 years) and long term effects (more than 50 years). Given the wide variety of impacts, this temporal dimension must be adapted to each type of impact. For some impacts, short term means the month (toxicity) and for others 10 years (greenhouse effect). In the same way, the long term may be a few years (eutrophication, acidification) and for others more than 1000 years (radioactivity).

d) The causal dimension
Is the effect **direct** or **indirect**? Does the flow have a direct impact on the target or does it damage the target indirectly through one or more intermediate effects?
The direct effects are said to be of zero order. If there is an indirect impact after an effect, it will be said to be of the first order and so on... (see the cascade of effects of SO_2).
This dimension is not redundant with the previous one. These two dimensions are far from always being correlated, as the passage from one order of impact to another does not take the same time from one cascade to another. In fact, we prefer this dimension to the temporal dimension.

e) Knowledge of environmental processes
We have identified **three cases** [7]:

1) The process is observable and observed. We are certain it belongs to the cascade of effects of the environmental flow: The effect is CONFIRMED (acute toxicity, acid rains, radiative forcing increase).
2) The process is not observed, scientific data allows us to state that it belongs to the cascade of effects of the environmental flow; it is UNCONFIRMED (carcinogenocity due to ozone depletion).
3) The process is not observable (for very long term effects, for example), it is prone to disturbances by non-human factors and/or it is only supposed that it belongs to the cascade of effects of the flow; it is POSSIBLE (global warming).

Now, we will use these remarks to propose new classification rules.

4.2 Rules for building a coherent family of environmental criteria

From these considerations, a coherent family of environmental criteria must be built. This task is carried out by analyzing the results from the inventory. The classification stage is not just a sorting of impacts into categories, but the assignment of inventory flows to impact categories which will form a coherent family of criteria.

Preliminaries
The family of criteria must be common to all the deciders. Due to the complexity of decisions to be made in environmental issues, a constructive approach [11] is the best solution for classification improvement. There are **two types** of dependencies between criteria:

- Dependencies due to structural or statistical relationships between criteria (mathematical relationships, for example,
- dependencies due to a system of values linking the preferences relative to the axes of significance of certain criteria to aspects of external consequences (the reasoning that "all things are equal elsewhere" is impossible).

In a **constructive approach**, all the dependant criteria (first type) must be conserved [11]. This is not a weakness of the family as long as these criteria interest different actors. The second type of dependencies exists when the result of the comparison of two actions according to a criterion depends on the performances obtained by these actions on other criteria in the family. In the opposite event, it is said that we satisfy the **isolation principle.**

In the **constructive approach,** this type of dependence does not satisfy the exhaustivity requirement [2][11]. This type of criterion cannot be accepted (case of raw material consumption). Therefore, one or several criteria must be added to satisfy this requirement, i.e. an axe of significance must be added. **Thus, for LCA classification, we must respect the isolation principle.** We will now give some advice in order to satisfy this **principle** for environmental criteria. It is impossible to propose a ready-made "recipe" to build a coherent family of criteria. This would be contrary to the very principles of a multicriteria, decision-making tool as presented by ROY [2], as it would mean imposing a family of criteria on the actors even before any discussion took place.

The Rules

However, we propose some rules to be respected in order to build the family easily. These rules are the translation of the three requirements: Exhaustivity, cohesion and non-redundancy for LCA classification.

1) **To take into account all the inventory flows** in the impact analysis (to reach exhaustivity).
2) **To establish cascades the effects of all the substances** in the inventory (in coherence with the characterization state of the art).
3) **To retain one impact for each branch of a cascade of effects.**
4) **To begin the classification by stressors with the simplest cascade of effects** (to keep the choice between effects, it enables to be sure to that these stressors take into account the classification) (to ease cohesion).
5) To try to **only take into account low impacts** (direct or indirect of the first order) to avoid dependencies between impacts. Of course this often means ignoring long term impacts, but such impacts are not correctly evaluated at the present date and are often highly dependant on non-human factors.
6) For a given substance, **impacts on parallel branches can be retained** without any theoretical restrictions. However, taking successive impacts into account is more tricky. We consider that **successive impacts cannot be isolated.**
7) **When it is decided that an effect is retained as a criterion, this effect must be retained for all the cascades of effects** in which it appears. To proceed, however, it would otherwise lead to **defaults in isolation** between the impacts of these substances.
8) **To beware of overlapping impacts** (too vague), such as ecotoxicity or the decrease in biodiversity. To retain an impact such as acidification and ecotoxicity for the same substance would be a mistake, as these are dependant impacts (to judge ecotoxicity, it is necessary to know the acidifying properties of a substance). Therefore, acidification must be integrated in a wider ecotoxicity criterion or ecotoxicity must be divided into multiple criteria (acute or chronic ecotoxicity...). We recommend the second solution in this case, as toxicity deserves greater attention (the sensitivity of the flora and fauna is very different). Biodiversity is not only dependent on man and cannot be attributed to a single activity. External factors must be considered in order to judge the impact on biodiversity.
9) **To retain only confirmed or unconfirmed impacts for** LCA according to the state of present scientific knowledge (eliminating possible impacts). Only confirmed impacts would be better.
10) **To eliminate impacts to which no preference structure can be attributed.** This is the case, for example, for the impact of consumption of raw materials. It is impossible to judge if the consumption of a ton of steel is worse (from an environmental point of view) than that of a ton of sand. We are able to do this, but only on integrating criteria of resource renewal and the state of reserves. Consequently, these three axes of significance (renewal, consumption and reserves) must be taken into account by a single criterion called damages to the patrimony (or depletion of reserves), for example. A new criterion can also be created for each case of renewal.

These rules can be considered as the conditions necessary to obtain a coherent family of environmental criteria which can be used for LCA. However, these conditions are not sufficient. The goal and scope definition is very important to help the actors to establish their family of criteria. Furthermore, the exhaustivity requirement is not often satisfied because certain flows from the inventory are not translated into environmental impacts through a lack of knowledge or precision of data.

5 General Conclusion

We have shown the similarities between the models of multicriterial decision-making tools and LCA. We have applied the constructive approach to propose a list of a few necessary rules in order to establish a coherent family of environmental criteria which can be used within the LCA framework. We have started a logical approach which is intellectually coherent as far as classification is concerned. This family of criteria will be different from one study to another, as it results from the thought and discussion of all the actors involved in decision making. Even if the same criteria will be used in most studies, this methodology enables one to justify this choice.

The practitioner's task is fundamental as it is his responsibility to determine the cascades of effects and propose criteria according to the existing modeling methods and without taking into account the preferences of each and every actor. For these approaches to be operational, the modeling methods of consequences need to progress, and a knowledge of impact mechanisms must improve.

This methodology promises to be more transparent with a better integration of environmental considerations in decision making.

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